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Power, people and pollutions

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Abstract

The harsh climate in Sudan presents unique challenges in meeting growing demands for power and water. The international demand of water increases compared to the available water resources, due to recent development water resources for different uses. In many areas especially in Red Sea areas, there is serious a shortage of potable water. These areas are enjoyed with a high intensity of solar energy. The move towards a de-carbonised world, driven partly by climate science and partly by the business opportunities it offers, will need the promotion of environmentally friendly alternatives, if an acceptable stabilisation level of atmospheric carbon dioxide is to be achieved. This requires the harnessing and use of natural resources that produce no air pollution or greenhouse gases and provides comfortable coexistence of human, livestock, and plants. This study reviews the energy-using technologies based on natural resources, which are available to and applicable in the farming industry. Among these are greenhouses, which are necessary for the growth of some plants (i.e., vegetables, flowers, etc.), in severe climates. Globally, buildings are responsible for approximately 40% of the total world annual energy consumption. Most of this energy is for the provision of lighting, heating, cooling, and air conditioning. Increasing awareness of the environmental impact of CO_2 and NO_x emissions and CFCs triggered a renewed interest in environmentally friendly cooling, and heating technologies. Under the 1997 Montreal Protocol, governments agreed to phase out chemicals used as refrigerants that have the potential to destroy stratospheric ozone. It was therefore considered desirable to reduce energy consumption and decrease the rate of depletion of world energy reserves and pollution of the environment.

Keywords: Sudan; Energy potential; Environment; Future prospect

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1. Introduction

Energy issues affect every aspect of modern society. These issues have been of primary concern, since the second oil crisis and the Gulf War. Energy problems are associated

with distribution, access, and security of supply. Particularly for the energy-deficient countries and remote islands/areas, renewable energy appears to be sustainable and a clean source of energy derived from nature. The utilisation of available renewable energy sources like solar, wind and biomass energy is of practical importance for future socio-economic development of the country. Sudan is an agricultural country with fertile land, plenty of water resources, livestock, forestry resources, and agricultural residues.

Energy is one of the key factors for the development of national economies in Sudan. Energy sources are divided into two main types; conventional energy (biomass, petroleum products, and electricity); and non-conventional energy (solar, wind, hydro, etc.). Sudan possesses a relatively high abundance of sunshine, solar radiation, and moderate wind speeds, hydro, and biomass energy resources. Application of new and renewable sources of energy available in Sudan is now a major issue in the future energy strategic planning for the alternative to the fossil conventional energy to provide part of the local energy demand. Sudan is an important case study in the context of renewable energy. It has a long history of meeting its energy needs through renewables. Sudan's renewables portfolio is broad and diverse, due in part to the country's wide range of climates and landscapes. Like many of the African leaders in renewable energy utilisation, Sudan has a well-defined commitment to continue research, development, and implementation of new technologies. Sustainable low-carbon energy scenarios for the new century emphasise the untapped potential of renewable resources. Rural areas of Sudan can benefit from this transition. The increased availability of reliable and efficient energy services stimulates new development alternatives.

Among the renewable energy sources, biomass seems one of the most interesting because of its share of the total energy consumption of Sudan is high at 87%, and the techniques for converting it to useful energy are not necessarily sophisticated. Implementation of biomass-based energy programmes will not, of course, be a definitive solution to the country's energy problem, but it will bring new insight for efficient energy use in the household sector, especially in rural areas where more than 70% of the population live (25 million). The estimates are based in the recoverable energy potential from the main agricultural residues, livestock, farming wastes, forestry and wood processing residues, and municipal wastes.

Fuelwood, animal wastes, agricultural crop residues, and logging wastes have been used through direct burning in Sudan for many years. These sources are often called non-commercial energy sources, but in Sudan fuelwood is a tradable commodity since it is the primary fuel of rural areas and the urban poor section. Traditional fuels predominate in rural areas; almost all biomass energy is consumed in the household sector for heating, cleaning and cooking needs of rural people. Especially in the villages (households on the high plateau) the preparation of three stone fires is very attractive to the villagers. In this method, food and plant residues are put in a large boiler with water and cooked on a traditional stove at the outside the house for animal feed, because cooked food and plant residues are cheaper than flour and bran. Nevertheless, this method consumes much more fuelwood than the cooking on the stoves method. On the other hand, wood is the most practical fuel for serving a large number of people because the size of the batch of food is only limited by the volume of the pot and not by the size of the stove's burner. Fuelwood is also convenient for cooking of the meal of meat as a cutlet meatball and meat roasted on a revolving vertical spit.

Special attention should therefore be given to reviewing forest resources, plantation programmes and the possibilities of substitution of fuelwood for commercial fuels or for

other fuels such as biogas. The main sources of fuelwood supply in the country can be broadly be grouped into two main categories, i.e., forest sources (forests under the control of forest departments) and non-forest sources (private farmland and wild lands). Women, assisted by children almost always, perform the gathering of fuelwood in rural areas of developing countries. As fuelwood becomes scarce, which is the case in many parts of the world, the collection time has increased and although men do not perceive it, this has many undesirable consequences, which can be clearly seen in many rural region of Sudan. Women have less time for their other important functions, such as cooking, washing, water collection, and child rearing which may affect the nutrition and health of the entire family. Wood energy is, for many countries, one of the few locally available sources of energy, which they can afford. Its substitution by imported fossil fuels, as has often been carelessly recommended, should attentively be evaluated to avoid undesirable political, economic and social consequences.

2. Geographic profile of Sudan

Sudan is the largest country in Africa with an area of approximately one million square miles (2.51×10^6 million km^2). It lies between latitudes 3°N and 23°N and longitude 21°E and 39°E (Fig. 1). Sudan's climate is very hot, every part of the country experience maximum average temperatures of over 38 °C during several months of the year and many parts experience these temperatures at all times of the year. In the north, the heat is tempered by low humidity during much of the year. Also, Sudan has a tropical continental climate for narrow fringe along the Red Sea coast. According to the last census the total population of Sudan estimated to be about 40,187,486 millions inhabitants (Table 1) [1]. The annual population growth rate is about 2.88% and the population density is 14 persons per km^2.

Sudan is considered one of the least developed countries, with a per capita income of less than US $400, and a real growth rate of 0.2% of real gross domestic product (GDP) during the last 10 years. However, during 1980s the real growth rate of GDP was negative mainly due to drought and desertification. The backbone of Sudan's economy is its agricultural sector. The agricultural sector determines to a great extent the economic performance of the Sudanese economy. In fact the country can be rescued by proper organisation and utilisation of its agricultural potential. Recent development due to rehabilitation and improvement in the agricultural sector has raised the share to 41%.

Agriculture continues to play a pivotal role in economy. It directly influences the level of activities of all other sectors. It provides 90% of the raw materials for local industries, accounts 80% of export earning, and provides income and employment for more than 80% of the population. The agricultural sector is composed of three distinct modes: Irrigated agriculture, mechanised rain-fed agriculture, and traditional rain-fed agriculture and livestock raising. Sudan is an agricultural country with fertile land, plenty of water resources, livestock, forestry resources, and agricultural residues.

To ensure a better quality of life for all people, now and in the future, through the implementation of sustainable development initiatives that promote:

- food, water and energy security;
- environment integrity;
- economic efficient that helps to eliminate inequalities;

Fig. 1. Geographical location of the Republic of Sudan.

Table 1
Total population in different Sudan regions (10^6 inhabitants)

Northern states	
Northern	4.298
Central	7.433
Eastern	5.567
Kordofan	5.323
Darfur	5.284
Khartoum	6.512
Southern states	
Bahr El Gazal	1.913
Upper Nile	1.258
Equatorial	2.599

Source: Central Bureau of Statistical & UNFPA [1].

- social equity for all, regardless of race, gender, disability or creed;
- democracy;
- environmental justice;
- effective education for environmentally and socially responsible citizenship; and
- mutual understanding between people.

Table 2
Expected population growth rate (1993–2018)

Year	Growth rate (%)
1983/1993	2.88
1993/1998	2.73
1998/2003	2.63
2003/2008	2.53
2008/2013	2.40
2013/2018	2.22

Source: Statistical Department [2].

According to the medium scenario population is going to grow as in Table 2.

Sudan is rich in water and land resources. Water resources is estimated at 84 billion cubic metres, this including the River Nile and its attributers, ground water beside the rain, which ranges from 0 mm in the Northern desert to a bout 1400 mm in the Equatorial region. The land used in the country is classified into four main categories, these are:

Category	Area (10^3 ha)
Arable land	8400
Pasture	29,940
Forest	91,560
Others	38,220

Source: Statistical Department [3].

Sudan is also viewed as one of the potential richest countries especially in livestock beside water and land. In 1997 the livestock estimation is as follows:

Type	Number of head (10^3)
Cattle	33,102
Goats	36,037
Sheep	39,835
Camels	2936
Total	111,910

Source: Central Bureau of Statistical & UNFPA [1].

Sudan is still considered as one of the 25 most developing African countries. Agriculture is the backbone of economic and social development in Sudan. About 80% of the population depend on agriculture, and all other sectors are largely dependant on it. Agriculture contributes to about 41% of the gross national product (GNP) and 95% of all earnings. Agriculture determines for the last 30 years the degree of performance growth of the national economy.

General features of energy sector:

- increase gap between supply and demand;
- high demand on energy;
- low efficiency in consumption device;
- household is the largest consuming sector of biomass and electricity;
- low afforestation rate;
- fuel-wood is common in household and service sectors and small industries;
- fuel prices are rapidly increasing include fuelwood and charcoal prices; and
- rapid depletion of forests in Khartoum, Central and Eastern States.

3. Energy situation

Sudan meets approximately 87% of its energy needs with biomass, while oil supplies 12%, and the remaining 1% is produced from hydro and thermal power. Sudan like most of the oil importing countries suffered a lot from sharp increase of oil prices in the last decades. The oil bill consumes more than 50% of the income earnings. The household sector consumed 60% of the total electricity supplies [4]. The total annual energy consumed is approximately 11.7×10^6 ton of oil, with an estimated 43% lost in the conversion process [5]. The heavy dependence on biomass threatens the health and future of domestic forests, and the large quantities of oil purchased abroad causes Sudan to suffer from serious trade imbalances. Poverty and iniquity in the basic services are the major components that hindered rural development. None of the great goals of the international and national community peace, human rights, environment, and sustainable development will be achieved or even progressed unless being addressed now. Energy is a vital prime mover to the development whether in urban or rural areas. The rural energy needs are modest compared to urban. A shift to renewables would therefore help to solve some of these problems while also providing the population with higher quality energy, which will in turn, improve living standards and help reduce poverty. For proper rural development the following must be considered:

- Analyse the key potentials and constraints on development of rural energy.
- Assess the socio-technical information needs for decision-makers and planners in rural development.
- Utilise number of techniques and models supporting planning rural energy.
- Design, import and interpret different types of surveys to collect relevant information and analyse them to be an input to planners.

3.1. Energy policy and strategy

Energy policy within the overall development policy of the National Comprehensive Strategy (1992–2002), has the following objectives:

- To provide an adequate and reliable supply of energy from local resources to support sustainable development.
- To conserve the environment through efficient and optimal utilisation of local resources, especially forests, and to promote tree-plantation activities. The solution of the energy problem should not be at the cost of the deterioration of natural resources.

- To conserve all energy types so as to generate the highest economic value for energy and minimise the cost to the economy.
- To develop the energy sector institutions to ensure coordination between consumers and producers.
- To develop and promote local and/or adapted energy technologies particularly in the field of renewable energy technologies (RETs).
- To train qualified and adequate staff at all levels to facilitate the development of energy sector.

3.2. *Energy resources*

The utilisation of available renewable energy sources like solar, wind and biomass energy is of practical importance for future socio-economic development of the country. Sudan is an agricultural country with fertile land, plenty of water resources, livestock, forestry resources, and agricultural residues. Energy is one of the key factors for the development of national economies in Sudan. Energy sources are divided into two main types: conventional energy (biomass, petroleum products, and electricity); and non-conventional energy (solar, wind, hydro, etc.). Sudan possesses a relatively high abundance of sunshine, solar radiation, and moderate wind speeds, hydro, and biomass energy resources.

3.2.1. *Non-commercial resources*

Non commercial resources includes fuelwood (which composed of fire wood and charcoal) beside agricultural residue and animal dung are utilised as fuel sources clearly dominating Sudan final energy consumption 66% and represent 78.6% from the energy supplies in 1997. Early estimates dating from the 1950s and 1960s indicated a productive forest area of 455,000 km^2. This area was to contain a growing stock volume of 1.28 million cubic metres. Average stocking 22.2–28.6 m^3/ha ranging from 150 m^3/ha in the forests in the south to less than 1 m^3/ha in the desert areas. The studies using early 1970s landsite photoimaginary, estimates the total area and volume of Sudan's forest resources to be about 1.08 million ha and 1.96 million m^3, respectively, about 70% of this is located in the Southern States and the forest area decrease towards the north of Sudan. Other biomass resource agriculture waste (include crop residue which composed of cotton stocks, groundnut shells, bagasse and animal dung) is the most eligible sources for non-wood biomass energy.

3.2.2. *Renewable energy resources*

Application of the new and renewable sources of energy available in Sudan is a major issue in the future strategic planning for an alternative to the fossil conventional energy to provide part of the local energy demand. Sudan is an important case study in the context of renewable energy. It has a long history of meeting its energy needs through renewables. Sudan's renewables portfolio is broad and diverse, due in part to the country's wide range of climates and landscapes. Like many of the African leaders in renewable energy utilisation, Sudan has a well-defined commitment to continue research, development, and implementation of new technologies. Sustainable low-carbon energy scenarios for the new century emphasise the untapped potential of renewable resources. Rural areas of Sudan can benefit from this transition. The increased availability of reliable and efficient energy services stimulates new development alternatives.

3.2.3. Solar energy

Since measurements and long-term records of solar radiation data for most parts of Sudan are not available, the existing correlation relations and models are used for estimating and evaluating solar radiation. Good agreement is achieved when the results of such models are compared with some measured data for solar irradiance. Referring to these models and other studies and measurements on radiation as well as to the variation in the topography and climatology of Sudan, the country has three climatatological regions [4,5]:

Region 1 is situated north of latitude 19°N. The summers are invariably hot (mean max. 41 °C and mean min. 25 °C with large decimal variation; low relative humidity averages 25%). Winters can be quite cool. Sunshine is very prevalent. Dust storms occur in summer. The climate is a typical desert climate where rain is infrequent and diurnal (annual rainfall of 75–300 mm). The annual variation in temperatures is large (maximum and minimum pattern corresponding to winter and summer). The fluctuations are due to the dry and rainy seasons. This region has the highest solar insulation in the country and has the lowest value of diffuse irradiance. In this regard, the annual daily average values of global irradiance are between 6.34 and 7.65 kWh/m^2 day for the direct beam component.

Region 2 is situated south of latitude 19°N. The climate is a typical tropical continental climate. Annual daily average values of about 5.92 kWh/m^2 day for global irradiance.

Region 3 comprises the areas along the Red Sea coast and eastern slopes of the Red Sea hills. The climate is basically as in region 1, but it is affected by the maritime influence of the Red Sea. Annual daily average values of about 5.80 kWh/m^2 day for global irradiance.

Sudan has been considered as one of the best countries for exploiting solar energy. The sunshine duration is ranging from 8.5 to 11 h/day, with high level of solar radiation regime at an average of 20–25 MJ/m^2 day on the horizontal surface. The annual daily mean global radiation ranges from 3.05 to 7.62 kW/m^2 day. However, Sudan has an average of 7–9 GJ/m^2 year, equivalent to 436–639/Wm^2 year [5]. The country strives hard to make use of technologies related to renewable sources in rural areas where it is appropriate and applicable. The most promising renewable energy technology are related to thermal systems; industrial solar water heaters, solar cookers, solar dryers for peanut crops, solar stills, solar driven cold stores to store fruits and vegetables, solar collectors, solar water desalination, solar ovens, and solar commercial bakers. Solar PV system: solar PV for lighting, solar refrigeration to store vaccines for human and animal use, solar PV for water pumping, solar PV for battery chargers, solar PV for communication network, microwave, receiver stations, radio systems in airports, VHF and beacon radio systems in airports, and educational solar TV posts in some villages [6].

3.2.4. Wind energy

Sudan is rich in wind; mean wind speeds of 4.5 m/s are available over 50% of Sudan, which is well suited for water lifting and intermittent power requirements, while there is one region in the eastern part of Sudan that has a wind speed of 6 m/s, which is suitable for power production. In areas where there is wind energy potential but no connection to the electric grid the challenge is simplicity of design, and higher efficiency. Because of this potential for fulfilment of rural water pumping needs, it is recommended to continue the

development of wind pumping in Sudan. The most obvious region to start with seems to be the northern regions because of a combination of:

- favourable wind regime;
- shallow groundwater level 5–10 m depth;
- existing institutional infrastructures.

The research and development in the field of wind machines should be directed towards utilising local skills and local available materials. Local production of wind machines should be encouraged in both public and private organisations.

3.2.5. *Mini-hydro energy*

Hydro potential is promising in Sudan. A number of prospective areas have been identified by surveys and studies carried for exploration of mini-hydropower resources in Sudan. Mini and micro-hydro can be utilised or being utilised in Sudan in two ways:

- Using the water falls from 1 to 100 m; energy can be generated, and small power can be generated up to 100 kW.
- Using the current flow of the Nile water, i.e., the speed of the Nile water. The water speed can be used in run-of the-river turbines (current river turbines), and then water can be pumped from the Nile to the riverside farms. There are more than 200 suitable sites for utilisation of current river turbines along the Blue Nile and the main Nile.

The total potential of mini-hydro shows 67,000 MWh for southern region, 3785 MWh in Jebel Marra area, and 44,895 MW in El Gezira and El Managil canals. Small-scale hydro plants (under 5 MW) are more environmentally benign than the large-scale hydro projects that often involve huge dams and permanent restructuring of the landscape. These smaller plants are perfectly suited for some regions of Sudan where there is plenty of rainfall and a mountainous or hilly landscape such as Jebel Marra. The hydropower is consumed in Khartoum, Central and East states.

3.2.6. *Geothermal energy*

Geothermal heat is constantly disputed from sources within the earth crust in regions where volcanic activity have taken place in relatively recent times. A tectonic movement accompanied by intensive volcanic activity took place in the Red Sea area about 25 million year ago. These conditions render the area a prospect for geothermal exploitation. Other parts of the country were affected by volcanic complex that is likely to process geothermal heat source stored at a relatively shallow depth, i.e., Red Sea area where the volcanic complex covers an area of 10,000 km^2 with an elevation of 3020 m above sea level. Hot springs and fume roles have been observed on the flanks. Also in Jebel Marra where volcanic complex processes an important geothermal heat source suitable for electric power generation.

3.3. *Energy balance*

In 1998 the estimated total energy supply was about 14.595 million tons of oil equivalent (TOE) (Table 3). Biomass (wood, animal waste) and the agriculture residues remained the

Table 3
Estimated energy supply 1998 resource supply (10^3 TOE)

Wood	12,152.83
Residues	798.5
Petroleum	1555.11
Hydro	90.1
Total	14,595.100

Source: National Energy Affairs Directorate [7].

Table 4
Energy consumption by sector (10^3 TOE)

Sector	Household	Services	Transport	Industry	Agriculture	Total
Petroleum	22	69	694	177	180	1142
Electricity	53	33	—	27	3	6
Wood	2522	691	—	217	—	3430
Charcoal	2150	154	—	—	—	2304
Residue	641	—	—	157	—	798
Total	5388 (69%)	947 (12%)	694 (9%)	578 (8%)	183 (2%)	7790 (100%)

Source: National Energy Affairs Directorate [7].

major contributor with the share of 88% (83% wood and 5% residues). This is a clear indication of continues exploitation of the country's forest resources. Petroleum and hydro provided 12% and 1%, respectively, of the total energy supply.

3.4. Total energy consumption

On the other hand consumption estimates during the period 1998–2000 was about 7790 thousand TOE (10^3 TOE) as shown in Table 4. The difference between supply and consumption is 6805 (10^3 TOE) (46.6%) reflects the losses and the low efficiency of utilisation of energy resources (only 53.4%). The most of the losses occurring in the process of converting wood to charcoal where more than 6.4 million TOE has been lost. On sectoral basis, household sector is the largest consuming sector with the largest share 69%. Biomass (wood, charcoal and residues) represents 98% of the total energy consumption in this sector and 81% of the total biomass consumption about 46% of the total electricity consumption. Services sector consumed 12% of the total energy consumption about 89% come from biomass and 28% of the total electricity consumption. Services consumed only 6% of the total petroleum consumption in 1998. The transportation sector constitutes 694 (10^3 TOE) all of it in the form petroleum products of the total energy consumed in 1998. It absorbed more than 60% of the total petroleum consumed in 1998. The industrial sector consumed only 578 (10^3 TOE) (8%) of the total energy consumed during the same year. It consumed only 6% of the total biomass consumption and 15 % of the total petroleum consumed and 23% of the total electricity. The agriculture sector consumption was only 182 (10^3 TOE) (2%) of the total country

energy consumption in 1998. Most of the consumption (98%) was petroleum products for water lifting in agricultural operations. The rest (2%) is electricity, which is used for water lifting only.

4. Major energy consuming sectors

Sudan is still considered as one of the 25 most developing African countries. Agriculture is the backbone of economic and social development in Sudan. About 80% of the population depend on agriculture, and all other sectors are largely dependant on it. Agriculture contributes to about 41% of the GNP and 95% of all earnings. Agriculture determines for the last 30 years the degree of performance growth of the national economy.

4.1. Agriculture sector

During the last decades agriculture contributed by about 41% to Sudan GNP. This share remained stable until 1984–1985 when Sudan was seriously hit by drought and desertification, which led to food shortages, deforestation, and also, by socio-economic effects caused the imposed civil war. The result dropped the agriculture share to about 37%. Recent development due rehabilitation and improvement in agricultural sector in 1994 has raised the share to 41%. This share was reflected in providing raw materials to local industries and an increased export earning besides raising percentage of employment among population. This sector consumed 2.5% of the total energy consumption (28% from electricity, 14.8% from fossil fuels, and the rest from biomass fuels).

4.2. Industrial sector

The industrial sector is mainly suffering from power shortages, which is the prime mover to the large, medium and small industries. The industrial sector was consuming 5.7% of the total energy consumption, distributed as follows: 55% from petroleum products, 13% from biomass and 32% from electricity.

4.3. Transport sector

The transportation sector (railways, ships, boats, etc.), was not being efficient for the last two decades because of serious damage happened to its infrastructure (roads, workshops, and maintenance centres, etc.). It consumed 10% of the total energy consumption and utilised 60% of the total petroleum products supplied.

4.4. Domestic use

Unlike other consuming sectors, the household sector has unique supply demand characteristics. These are mainly summarised as follows:

- The household sector consists of many individual users, where there is enormous diversity in the availability and cost of energy supplies, mix of fuels are employed at the level of consumption with different users and different technologies.

- Biomass dominated the household energy supply and consumption is not recorded and mostly the information is estimates or surveys, which is costly.
- Biomass was specially in the rural areas are competing with other uses such as animal fodder, timber, brick making, wall painting as well as fuels. So the energy problem and solutions must almost invariably be considered within the total content.
- Traditional household fuels and technologies for their use are often difficult to change, largely because of local awareness and alternatives are not known and there is no capital even if there is an alternative.

Household is the major energy consumer. It consumed 92% of the total biomass consumption in form of firewood and charcoal. From electricity this sector consumed 60% of the total consumption, and 5.5% of petroleum products.

5. Factors determine consumption

The following factors determine energy consumption in Sudan:

5.1. Urban and rural

Substitution options for household energy in Sudan urban dwellings are electricity, LPG, kerosene/gasoline and fuelwood. Rural towns and villages are the viable consumers of wood and charcoal. Due to unavailability or un-affordability of fuelwood in these areas household consumption was shifted towards agriculture residues.

5.2. Occupation

Occupation pattern are different in urban/rural areas. Housewives consider themselves unemployed, through they are occupied by household management and children raising (specially in rural area) are active in farms assisting their husband.

5.3. Income

Highest consumption of LPG and electricity is found in higher income households. For wood and charcoal the situation is the reverse, highest consumption by low-income group and lowest by high-income groups.

5.4. Education

It is quite evident that the share of illiteracy developed from 2.4% in high income households up to 58.9% in rural low income in systematic matter which shows a direct correlation between level of income, mode of living and education (result of household survey 1994). In general illiteracy rates are higher among rural population compared to urban, with levels around 40–45% except for Khartoum rural with 21% illiterate.

5.5. Family size

The increase in energy supplies especially biomass was mainly observed due to population growth which directly related to family size.

6. Energy consumption (rural and urban)

Petroleum consumption in household sector is mainly consumed in for lightening by using kerosene and gas oil lamps. LPG is used in household for cooking. The last 5 years reflect increasing consumption of LPG in household, due to encouragement investment policies in this area. Tables 5–7 show that LPG quantities were increase-tripled times in 1997–1994 consumption.

Urban household consumption from electricity sector is about 43–44% according to total electricity supplies from 1998 data. The main consumption is due to lighting,

Table 5
Per capita energy consumption (TOE/Annum)

Fuel type	Firewood charcoal	Agriculture residue & animal dung	Kerosene/gas oil	LPG
Semi desert	0.076	—	0.006	0.013
Low rain fall	0.069	0.0074	0.005	0.0006
Savannah	0.063	—	0.003	0.012
Tropical	0.047	0.02	0.0008	0.0004
Total (per capita/annum)	0.095	0.082	0.078	0.0682

Source: African Development Bank [8].

Table 6
Per capita consumption of fuels by income groups of rural and urban

Type	Rural	Urban
Firewood (kg)	0.011	0.046
Charcoal (kg)	0.487	0.247
LPG (kg)	0.131	0.001
Kerosene (gallon)	0.001	0.0055
Electricity (TOE)	0.147	0.015
Residues (TOE)	0.03	0.03

Source: African Development Bank [8].

Table 7
Petroleum consumption in household sector

Year	Household consumption	Total petroleum consumption	%
1993	23,859	1,214,892	2
1994	20,603	1,444,057	1
1995	22,144	1,352,086	2
1996	32,004	1,359,672	2
1997	33,179	1,443,520	2
1997	39,362	1,348,872	3

Source: National Energy Affairs Directorate [7].

refrigeration and ironing and a low percentage for cooking (Tables 8–10). In Sudan rural constitute about 70% of population surveys reflected that rural are depending upon fuelwood and charcoal rather for domestic use. Also, studies in 1995 showed that the gas share within household consumption is about 10%. A sharp jump occurred during the last 15 years, where the government policy encouraged private investment in LPG. The consumption of LPG is almost tripled in 1999 compared to 1985. This indicates new trends in energy consumption of this sector.

The poor situations of conventional energy supplies to Sudanese people are characterised by high dependence on biomass woody fuels (firewood, and charcoal). More than 70% of the total Sudanese population live in rural and isolated communities characterised by extreme poverty and economical activity [8]. The unavailability and the acute shortages of the conventional energy supply (petroleum and electricity) to rural people forced them to use alternatives available energy sources like biomass [9]. This

Table 8
Total electricity consumption in household sector (10^3 TOE)

Year	Household consumption	Total electricity consumption	%
1989	36.72	83.42	44
1990	46.96	106.64	44
1991	46.96	106.64	44
1992	47.64	108.27	44
1993	48.16	109.39	44
1994	47.39	107.76	44
1995	50.83	117.05	43
1996	54.61	124.1	44
1997	50.83	115.58	44
1998	50.65	115.07	44

Source: National Energy Affairs Directorate [7].

Table 9
Total biomass consumption in household sector (10^3 TOE)

Year	Fuelwood consumption	Charcoal consumption	Agriculture residue	Total household consumption	Total biomass	%
1989	2887.8	1443.9	48.1	4379.8	5177.8	85
1990	2963.8	1481.9	49.4	4495.1	5336.2	84
1991	3041.7	1520.9	50.7	4613.3	5497.7	84
1992	3121.7	1560.9	52.0	4734.6	5662.5	84
1993	3187.9	1593.9	53.1	4834.9	5805.5	83
1994	2815.6	1279.8	511.9	4607.3	5556.9	83
1995	2889.6	1313.5	525.4	4728.5	5720.3	83
1996	2965.7	1348.0	539.2	4852.9	5886.9	82
1997	3043.7	1383.5	553.4	4980.6	6056.9	82
1998	3123.7	1419.9	567.9	5111.5	6230.4	82

Source: National Energy Affairs Directorate [7].

Table 10
LPG consumption in household sector (10^3 TOE)

Year	MT	TOE
1985	7564	8169.12
1986	9724	10,501.92
1987	9839	10,626.12
1988	0,140	10,951.2
1989	10,579	11,425.32
1990	12,849	13,876.92
1991	11,640	12,571.2
1992	13,260	14,320.8
1993	12,139	13,110.12
1994	12,491	13,490.28
1995	15,197	16,412.76

Table 11
Final end use consumption in household sector

Activity	Urban (kg)	Urban (%)	Rural (kg)	Rural (%)
Cooking	1.88	65.51	3.07	84.34
Lightening	0.30	0.45	0.36	9.89
Refrigeration	0.33	11.50	0.00	0.00
Other	0.36	12.54	0.21	5.77
Total	2.87	100	3.64	100

Source: National Energy Administration (NEA) [11].

situation caused serious environmental degradation beside the poor unsatisfactory services of some basic needs such as: food security, water supply, health care, and communications.

In order to raise rural living standards, the per capita energy availability must be increased, through better utilisation of the local available energy resources (Table 9). The rural energy requirements are summarised in Table 10. The suitable energy source, needed for the above rural requirements must be of diffuse low cost types rather than large central installation. Also, those technologies must be appropriate, environmentally, socially and economically acceptable. The urgent problem for rural people development is to increase the energy available per capita. Since it is necessary to rise up the present level of extreme poverty and better basic need services (Tables 11 and 12).

7. Sudan second National Energy Assessment

The first National Energy Assessment for Sudan was conducted 1983. Since that, a lot of changes were observed concerning supply/demand pattern for energy. Those changes can be summarised into the following:

- increase in population and rate of urbanisation;
- change in pattern of industrial production;

Table 12
Household consumption by fuel type (10^3 TOE)

Fuel	Urban (kg)	Urban (%)	Rural (kg)	Rural (%)
Charcoal	1.46	51.05	1.88	51.37
Firewood	0.22	7.69	1.33	36.34
LPG	0.38	13.29	0.00	0.00
Kerosene	0.02	0.70	0.11	3.01
Gas oil	0.04	1.4	0.33	9.02
Electricity	2.57	25.87	0.00	0.00
Animal residue	0.00	0.00	0.01	0.27
Agriculture residue	0.00	0.00	0.00	0.00
Total	2.86	100	3.66	100

Source: National Energy Administration (NEA) [11].

- expansion in transport network (road);
- exploration of oil;
- implementation of Federalism in ruling the States (changes in administrative division);
- LPG is more popular in urban household.

The household energy assessment is being undertaken now as part of the overall energy assessment. The first assessment undertaken with a support from USAID, provided a good base of methodologies and type of data to be collected for establishing an energy balance of the country and formulating of future plans for the energy sector. The present household energy survey undertaken aims to achieve the following objectives:

- The general objective is to establish an information data lose for this sector, to enhance the country's overall policies and planning to promote an optimal and sustained development and management of energy source.
- The specific objective.
- Evaluate the consumption pattern.
- Evaluate level of consumption and factors influencing consumption for each type of fuel.
- Estimate variation in per capita consumption by states/urbanisation/socio-economic groups.
- Quantity consumption by end use.

8. On going activities

1. Organisation of the study work and implementation
   - Preparation for the study started in 1998.
   - As a subtechnical committee of the assessment project a household sectoral committee was nominated, representing experts in household surveys.
   - The subcommittee formulated a plan for conducting the study accomplished includes the following:
     (1) Design the sample for survey.
     (2) Design the questionnaires.

(3) Estimated budget and manpower for conducting the survey and analysis of data later.
(4) The plan was reviewed and approved by the National Energy Assessment Technical Committee, and latter by the National Steering Committee.
(5) The implementation of the fieldwork (data collection) was managed by the Central Bureau of Statistics and conducted through its offices in the different states.
(6) The data was collected for most of the states during the period June–July 1999, in Southern and West Darfur during winter 1999.
(7) The two types of questionnaires were developed the main household questionnaire, and sample area questionnaire.

The numbers of questionnaires conducted in household were:

16 Northern State*1500 = 24,000
3 Southern States*500 = 1500
Total = 25,500

The data collected was entered into the computers using Access Programme. The sample area questionnaire includes information about prices; weights and volumes of units of fuels used in the area-data of this questionnaire were completed and summarised.

2. Activities need to be accomplished next
   - To set a programme for analysing the data from main questionnaire.
   - Presentation of results on a report.
   - Publishing of the main report.
3. Efforts done within the household sector in the last 15 year
   The results of the First National Energy Assessment Project indicated that household constitute the greater consumer of biomass, electricity 80%, 44% respectively. Most of biomass consumption was noticed to be by rural household for cooking, boiling and baking. For electricity lighting and refrigeration are on the top list, ironing also noticed to constitute considerable amount of household electricity consumption.
   The efforts done include:
   - improved stoves;
   - biogas;
   - briquetting;
   - carbonisation;
   - energy plantations;
   - new challenges.

8.1. Improved stoves

Efforts with improved stoves started in 1980. A number of stoves were developed those are Dugga stove, Mubkhar stove, Sawdust stove, and Jiko stove (Kenyan Type). The plantation rates of those stoves in the household sector is less than 5%, and this due to:

1. Lack of trained artesian.
2. Lack of awareness in the area of conservation.

3. Lack of finance.
4. Some stoves are not practically used.
5. Unavailability of ceramic due to limited production since ceramic production required certain knowledge.

8.2. Biogas

Biogas technology was also introduced as a substitute for fuelwood in household sector. Few units were constructed with capacity ranging from 5 to 15 m^3 of gas production/day, and these were Indian design mostly. But the experience proved that the community size units are more economic than small units. New biogas units were developed as a mix between Indian/Chinese types. Still there is a room for biogas, because rural population in Sudan almost live in community extended family.

8.3. Briquetting

Two types of briquettes were tested in the household:

1. Direct briquettes.
2. Carbonised briquettes.

8.3.1. Direct briquetting

Briquetting technology introduce in Sudan 1980, by small enterprise using ground net shells. The factory worked for 2 years and stopped due to transport of ground net shells from a distance of 10 km. In 1988 GTZ with collaboration with Sudan introduced a briquetting machines with capacity of 2 tons/day to produce agricultural briquettes using groundnut shell in western Sudan since 1990 (80% of fuelwood). The factory was reported to work below capacity because the market is limited. The transportation of briquettes to other sites implies additional cost. Three other briquetting machines were introduced to Sudan in 1996. These machines were planted to use cotton stacks and bagasse. Marketing of briquettes is a problem because most of the factories were installed according to resource availability. A stove was design by a volunteer so as to use briquettes in household sector. It was proved that briquettes could substitute firewood only in rural households.

8.3.2. Carbonisation briquettes

Carbonised briquettes were also produced in 1988 with German NGOs GTZ. Cotton stalks were carbonised in kilns and briquetted using molasses as a blinder. The briquettes generate some smoke, but it has limited acceptance within rural housewives, when compared to charcoal, which is smokeless fuel.

8.4. Energy plantation

During 1984–86 the American agency (EDI) in collaboration with Sudan Government financed community forestry project to help small farmers to plant trees to conserve the land as well as to satisfy this energy needs. The project provides loans to about 50 farmers. It was succeeded to plant a considerable area but the work stopped by the end of the project.

8.5. New challenges

Sudan becomes one of the oil exporting countries since August 1999, producing about 150,000–180,000 barrels/day. A complex refinery was constructed in Khartoum, with capacity of 50,000 tons/day. An amount of 500 tons/day of LPG is expected to be produced. The demand was estimated at 100 tons/day (Figs. 2 and 3). This new situation requires certain activities to be taken.

According to pattern of energy consumption in household sector in Sudan as a results of studies and observations in that sector the following barriers are concluded:

- Lack of public awareness towards important of conservation concept.
- Lack of polices concerned with energy efficiency measures in household sector.
- Lack of experts and trained personal in such issues.

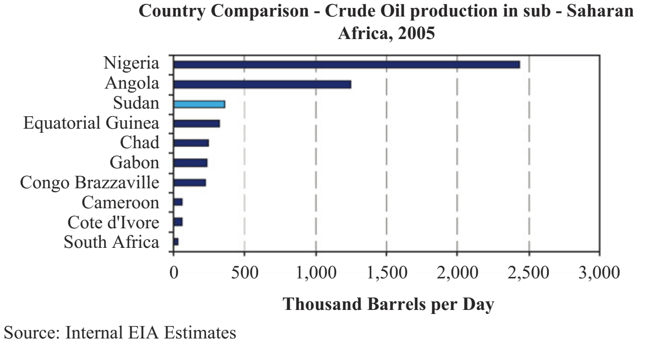

Fig. 2. Comparison of crude oil production in sub-Saharan countries [10].

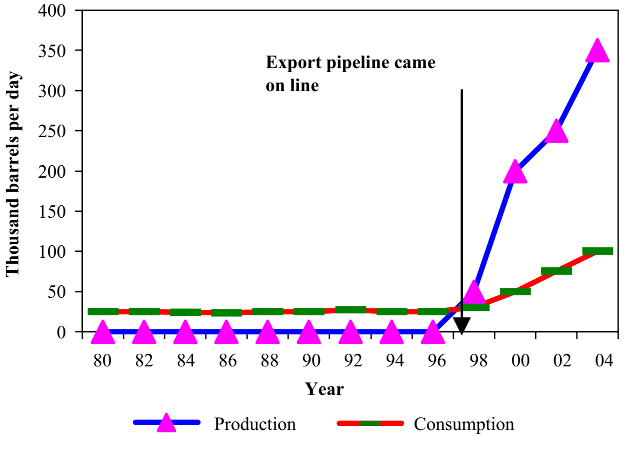

Fig. 3. Sudan's oil production and consumption 1980–2005.

Due to above-mentioned barriers and to get the maximum benefit from the recent assessment studies the following assistance are required:

- Under taking specialised studies (nomads, specific energy uses in household sector, seasonal surveys, etc.), to enriched the recent conducted surveys.
- To provide experts to evaluate the collected data and to participate in the analysis phase and report writing.
- To train NEA staff programme for energy modelling.
- To provide stationeries and equipments (computers, printers and software, etc.).
- Technical assistance to help in formulation and implementation of conservation policies (efficiency standards/legislations, pricing, etc.).
- To conduct certain programmes to raise the public awareness in the area of energy conservation within the household sector.
- To provide technical assistance in the area of research and development within conservation issues.

9. Sustainable development in Sudan

Like most African countries, Sudan is vulnerable to climate variability and change. Drought is one of the most important challenges. The most vulnerable people are the farmers in the traditional rain-fed sector of western, central and eastern Sudan, where the severity of drought depends on the variability in amount, distribution and frequency of rainfall. Three case studies were conducted in Sudan as part of the project. They examined the condition of available livelihood assets (natural, physical, financial, human and social) before and after the application of specific sustainable livelihood environmental management strategies, in order to assess the capacity of communities to adapt creased resilience through access to markets and income generating opportunities.

It is also important that sectoral and other development plans enforce rather than undermine community coping capacity. Sometimes a lack of integrated planning can lead to development in one sector at the expense of others. For example, at Arbaat in eastern Sudan, in its effort to address water shortages in Port Sudan (the capital city of the Red Sea State) and to improve its water supply, the government proposed heightening of a dam on a stream called Khor Arbaat, which local communities depended on for their livelihood. This plan would negatively impact the local community upstream, as it would reduce the area available for cultivation and could pose a real threat if long-term population increases occur. The local committee has proposed mitigation measures to the state authorities, including: digging wells to compensate people for lost water and provide permanent supplies to farms and home gardens; guaranteeing the farmers an agreed amount of water from the Khor Arbaat; and, compensating the region by providing social and economic services.

9.1. Priorities for Sudan development

The Africa Environment Outlook, 2002, also identifies a number of actions to reduce poverty and protect the environment. These include the improvement of infrastructure and sustainable human settlements, and the improvement of scientific and technological

Table 13
Sustainable development indicators

Economic	Human
• Gross domestic product growth • Sectoral development • Employment • Foreign exchange • Investments • Regional structure	• Education • Health • Capabilities: freedom, well-being, living standards
Environment	**Social**
• Air pollution • Water pollution • Waste discharge • Exhaustible resources • Biodiversity	• Local participation and sharing of benefits • Income distribution • Information sharing systems • Institutional capacity building

Source: The World Resources Institute 1992–1993 [12].

information. The strategic plan for capacity building drawn up by the New Partnership for Africa's Development also identifies the following priority areas:

- promotion of good governance;
- promotion of community-based natural resource management;
- prevention and management of conflicts; and
- promotion of integrated management of natural and man-made disasters and movement towards sustainable development.

Some of the priorities for Sudan development identified are listed below:

- Development plans must be in tune with Sudan's real needs and priorities.
- Win-win options are needed, which support both adaptation and development objectives.
- All major stakeholders must engage in national development planning processes using a combination of top-down and bottom-up approaches (Table 13).
- Improved communication and awareness among various stakeholders and encouraged cross-sectoral thinking to avoid conflicting development policies and plans.

The development of patterns of energy generation and use, which can be sustained into the future, is increasingly being seen as urgent, given growing concerns about the potential social and economic impacts of climate change. This article reviews the energy options for a sustainable future, focusing on options, which might reduce or limit the level of carbon dioxide emissions. The climate change issue is a global one and increasingly, developing countries will begin to contribute to it as they industrialise. However, the industrialised countries bear the responsibility for having developed the technologies that have created the problem. It would only be reasonable to expect them to play a leading role in developing some of the technologies, which might help to reduce it.

The basic criteria for the energy choices facing the world are, of course, not just environmental. Economic factors remain crucial. However, short-term economic prosperity may mean little if the health, well-being and livelihood of the populations concerned cannot be

maintained. At one time a major pre-occupation of many environmentalists was the fear that supplies of key fuels would soon be exhausted. Nowadays, although the price of fuels remains a key political issue, fuel scarcity is less of an immediate concern.

10. Climate change

The scale of fossil combustion has increased dramatically since the industrial revolution by a factor of more than 20 and unless changes are made to the way energy is generated and used, this growth seems likely to continue. In the industrialised countries, their use is split roughly equally between electricity generation (coal), heating (natural gas) and transport (oil), although gas is increasingly replacing coal for electricity generation and the transport sector is expanding continually. However, the use of fossil fuels creates environmental problems. In addition to problems with acid emissions, the combustion of fossil fuels in power stations and vehicle engines inevitably generates carbon dioxide gas and these emissions, along with other greenhouse gases like methane, are claimed to play a significant part in the process of global climate change that seems to be underway. Forestry is only one option for creating new biological carbon sinks. The adopting of different farming practices can also offer routes to carbon sequestration. In the end, despite its attractions, carbon sequestration might be seen as a rather inelegant approach to dealing with the problem of emissions-essentially trying to deal with the problem after the event. Surely it would be better not to produce so much carbon dioxide in the first place.

Some of this damage seems likely to occur whatever is now done, since the carbon dioxide imbalance that has already been created is likely to persist for some while (although there are continual interchanges between the air, the sea and the other carbon sinks, the net excess carbon dioxide can take many decades to be absorbed). Moreover, unless radical changes are made, the situation could be made even worse, as demand for energy increases. It is usually argued that it would be more effective in carbon mitigation terms to plant and then rapidly harvest fast-growing, short-rotation coppices of willow, and use these energy crops to produce electricity in a power plant, assuming the energy produced substituted for energy that would otherwise have been supplied using fossil fuels. Nevertheless, reforestation has its attractions as interim carbon store, since it is relatively cheap, assuming land is available, and it offers other benefits, such as enhanced biodiversity.

10.1. Energy efficient generation

The most direct way to reduce carbon dioxide production is by burning less fossil fuel. There are various ways in which this can be achieved. The simplest is for people to actually use less energy, i.e., to make do with lowered energy services, which implies something of a frugal approach to lifestyles. It is possible to use fossil fuels more efficiently, so as to get more useful energy for each ton of carbon dioxide produced, or to put it more positively, get the same amount of useful energy with less carbon emissions. This can apply both to generation and consumption. The classic example in terms of generation is combined heat and power (CHP), the co-generation of heat as well as electricity in power plants.

Worthwhile as CHP is, the electrical power industry has mostly preferred another option: switching over to medium-sized combined cycle gas turbines (CCGT), without CHP. The reasons for their popularity is that gas has been cheap and gas-fired turbines are quick to install: essentially they are jet engines driving a generator, with the hot exhaust

gases also used to produce steam for a conventional turbine, in a two-stage system. They are not as efficient as CHP, but are much better than conventional plants, achieving overall energy conversion efficiencies of 55% or more [13].

10.2. End use energy efficiency

Moreover, while there will hopefully be many technical and operational innovations than can improve efficiency, it is hard to see how efficiency improvements can be replicated continually, so as to keep pace with the projected 2% p.a. increase in basic global energy demand into the future.

Fortunately, we may not need to, in effect, create little Suns on Earth with fusion reactors. The Sun is a working fusion reactor that already supplies more energy than human beings could use, if technologies can be developed to tap it efficiently. The incoming solar energy drives the climate system, creates winds, waves and rain for river flows and sustains biomass growth. The use of these climate and weather-driven energy flows and sources would represent a rather elegant closing of a circle, since we are talking about using the climate and weather system to help us avoid climate change by substituting for the use of fossil fuels. Not all the natural energy flows available are climate driven. In addition to the continually renewed solar sources, the gravitational pull of the Moon on the sea results in tides: lunar power. Although not strictly a fully renewable resource, there is also the heat deep underground created by radioactive decay, a source of geothermal energy. The total energy available from the various renewable energy sources are very large.

While wind power has attracted most media attention, the use of biogas from biomass wastes has actually proved to be the most immediately economic option, with sewage gas and gas from landfill sites being amongst the cheapest renewable energy sources. Although also economically attractive, energy recovery via the combustion of municipal and domestic solid wastes has been less successful, mainly due to opposition by local residents concerned about the potential for emissions of dioxin from the combustion of plastics. In addition, most environmentalists do not see these wastes as genuinely renewable sources since they rely on the production of materials, which ought, they feel, to be avoided where possible, and recycled where not. One of the main uncertainties is over how the relative environmental costs of the various options will be assessed in future. If, for example, the full social and environmental cost of carbon dioxide and acid emissions from coal combustion were added to the cost of generation, then the comparisons would alter dramatically.

11. Conclusion

Sudan is an agricultural country and has good resources of energy from agricultural residues, forestry resources and animal wastes. Sudan has an excellent annual mean solar radiation of 5.44 kWh/m^2 day which could be of strategic important in substituting for oil, electricity, wood and charcoal and in assisting in rural development and in improving the quality of life in rural areas. Sudan is rich in wind; about 50% of Sudan's area is suitable for generating electricity (annual average wind speed more than 5 m/s) and 75% of Sudan's area is suitable for pumping water (annual average wind speed 3–5 m/s). Biogas plants offer renewable options that are relatively inexpensive and well suited to rural areas. Hydropower will continue to play a role in smaller-scale energy supply. There is also potential for expanding wind and solar applications in Sudan, particularly in rural areas.

Energy is one of the key factors for the development of national economies in Sudan. The use of renewable energy resources could play an important role in this context, especially with regard to responsible and sustainable development. It represents an excellent opportunity to offer a higher standard of living to the local people, and will save local and regional resources. Implementation of renewable energy technologies offers a chance for economic improvement by creating a market for producing companies, maintenance and repair services. Production of bio-fuels such as ethanol from sugar cane, takes advantages of year-round cultivation potential in a tropical country like Sudan. Benefits extend from local to regional to national to global. Local rural economies benefit through new economic opportunities and employment in the agricultural sector. Urban regions benefit through cleaner air and health improvements. The nation benefits through substituting domestic resources for costly imported gasoline. The world benefits from reduced CO_2 emissions.

In a country with a high population density, there are extreme pressures on energy and waste systems, which can stunt the country's economic growth. However, Sudan has recognised the potential to alleviate some of these problems by promoting renewable energy and utilising its vast and diverse climate, landscape, and resources, and by coupling its solutions for waste disposal with its solutions for energy production. Thus, Sudan may stand at the forefront of the global renewable energy community, and presents an example of how non-conventional energy strategies may be implemented. Energy efficiency brings health, productivity, safety, comfort and savings to the homeowner, as well as local and global environmental benefits.

Appendix A. Facts about Sudan

See Table A1

Table A1

Population	40,187,486 (2005 estimation)
Languages	Arabic (official), Nubian, Ta Bedawie, diverse dialects of Nilotic, Nilo-Hamitic and Sudanic languages
Religion	Sunni Muslim 70% (in north), indigenous beliefs 25%, Christian 5% (mostly in south and Khartoum)
Ethnic group(s)	Black 52%, Arab 39%, Beja 6%, foreigners 2%, other 1%
Currency/exchange rate	Sudan Dinar 228.570 SD = US $1
Inflation rate	8.0%
Consumer price index	7.1%
Gross domestic product	5.7%
Exports-commodities	Oil and petroleum products; cotton, sesame, livestock, groundnuts, gum Arabic, sugar
Energy-related CO_2 emissions	8.8 million metric tons, of which oil (100%), natural gas (0%), coal (0%)
Per capita, energy-related CO_2 emissions	0.3 metric tons
Environmental issues	Inadequate supplies of potable water; wildlife populations threatened by excessive hunting, soil erosion, desertification, periodic drought
Major environmental agreements	Party to: Biodiversity, Climate Change, Climate Change-Kyoto Protocol, Desertification, Endangered Species, Law of the Sea, Ozone Layer Protection signed, but not ratified: none of the selected agreements

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